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Volchegursky et al.

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(54) **PROVISION A VIRTUAL ENVIRONMENT BASED ON TOPOLOGY OF VIRTUAL NODES, NODE DEPENDENCIES AND BASE NODE CONFIGURATION INFORMATION**

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G06F 9/445 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 9/5072*** (2013.01); ***G06F 8/60*** (2013.01); ***G06F 8/61*** (2013.01); ***G06F 9/455*** (2013.01); *G06F 9/445* (2013.01); *G06F 2009/4557* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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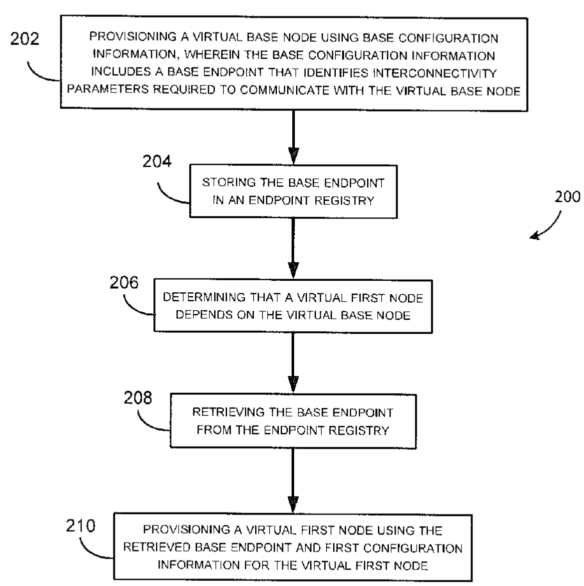
(57) **ABSTRACT**

A method for automatically provisioning a virtual computing environment comprising a plurality of virtual computing nodes includes provisioning a virtual base node using base configuration information that includes a base endpoint that identifies interconnectivity parameters required to communicate with the virtual base node, and storing the base endpoint in an endpoint registry. The method further includes determining that a virtual first node depends on the virtual base node, and receiving the base endpoint from the endpoint registry. Thereafter, the virtual first node is provisioned using the received base endpoint and first configuration information for the virtual first node.

20 Claims, 7 Drawing Sheets



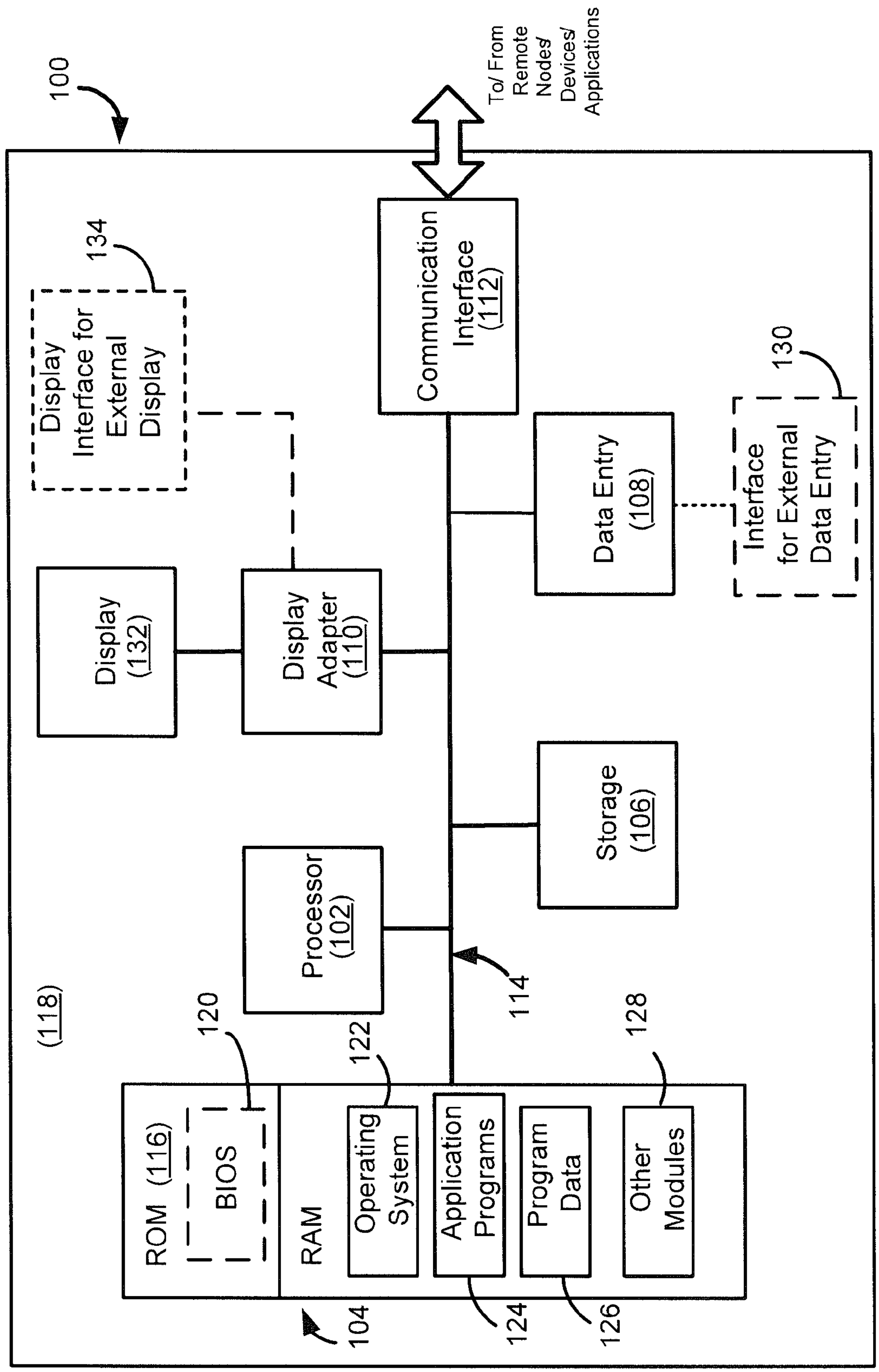

100
To/ From Remote Nodes/ Devices/ Applications
134
Display Interface for External Display
Communication Interface (112)
130
Display (132)
Display Adapter (110)
Data Entry (108)
Interface for External Data Entry
Storage (106)
Processor (102)
(118)
114
120
122
128
ROM (116)
BIOS
RAM
Operating System
Application Programs
Program Data
Other Modules
104
124
126

FIG. 1

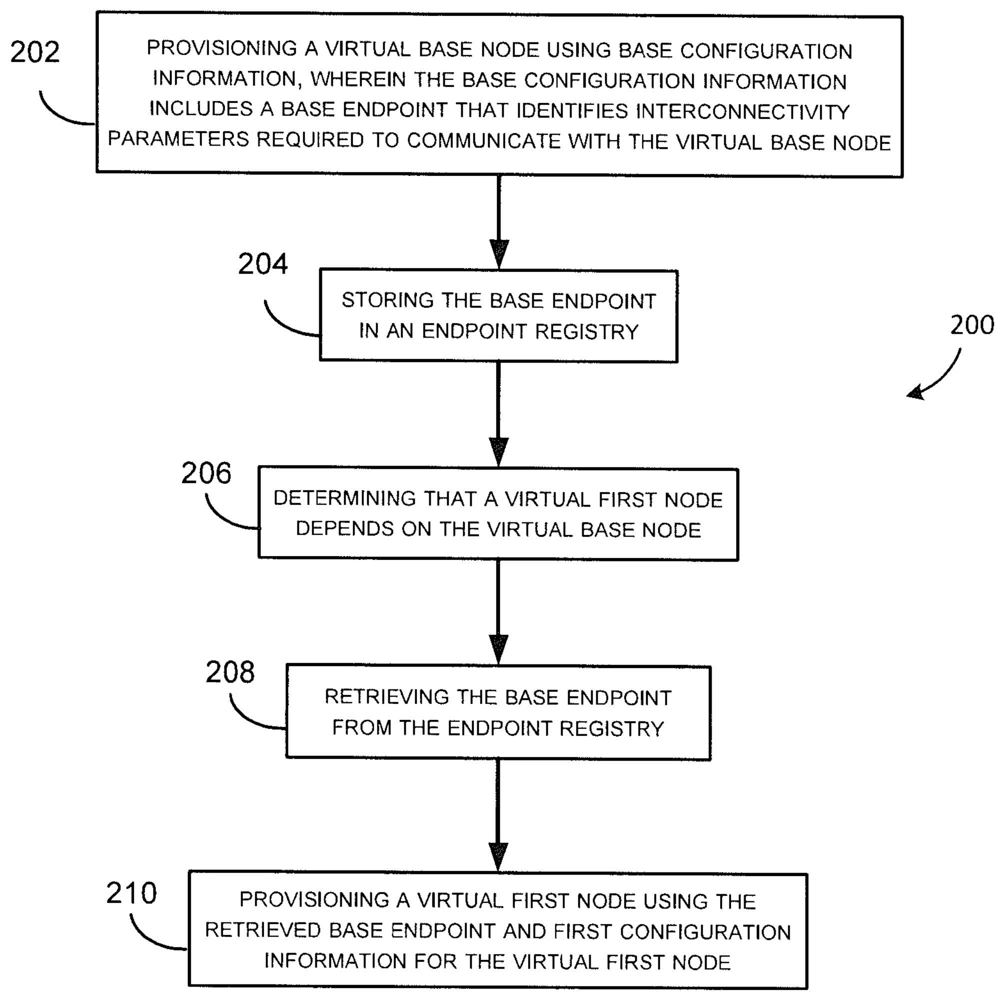

200
202
PROVISIONING A VIRTUAL BASE NODE USING BASE CONFIGURATION INFORMATION, WHEREIN THE BASE CONFIGURATION INFORMATION INCLUDES A BASE ENDPOINT THAT IDENTIFIES INTERCONNECTIVITY PARAMETERS REQUIRED TO COMMUNICATE WITH THE VIRTUAL BASE NODE
204
STORING THE BASE ENDPOINT IN AN ENDPOINT REGISTRY
206
DETERMINING THAT A VIRTUAL FIRST NODE DEPENDS ON THE VIRTUAL BASE NODE
208
RETRIEVING THE BASE ENDPOINT FROM THE ENDPOINT REGISTRY
210
PROVISIONING A VIRTUAL FIRST NODE USING THE RETRIEVED BASE ENDPOINT AND FIRST CONFIGURATION INFORMATION FOR THE VIRTUAL FIRST NODE

FIG. 2

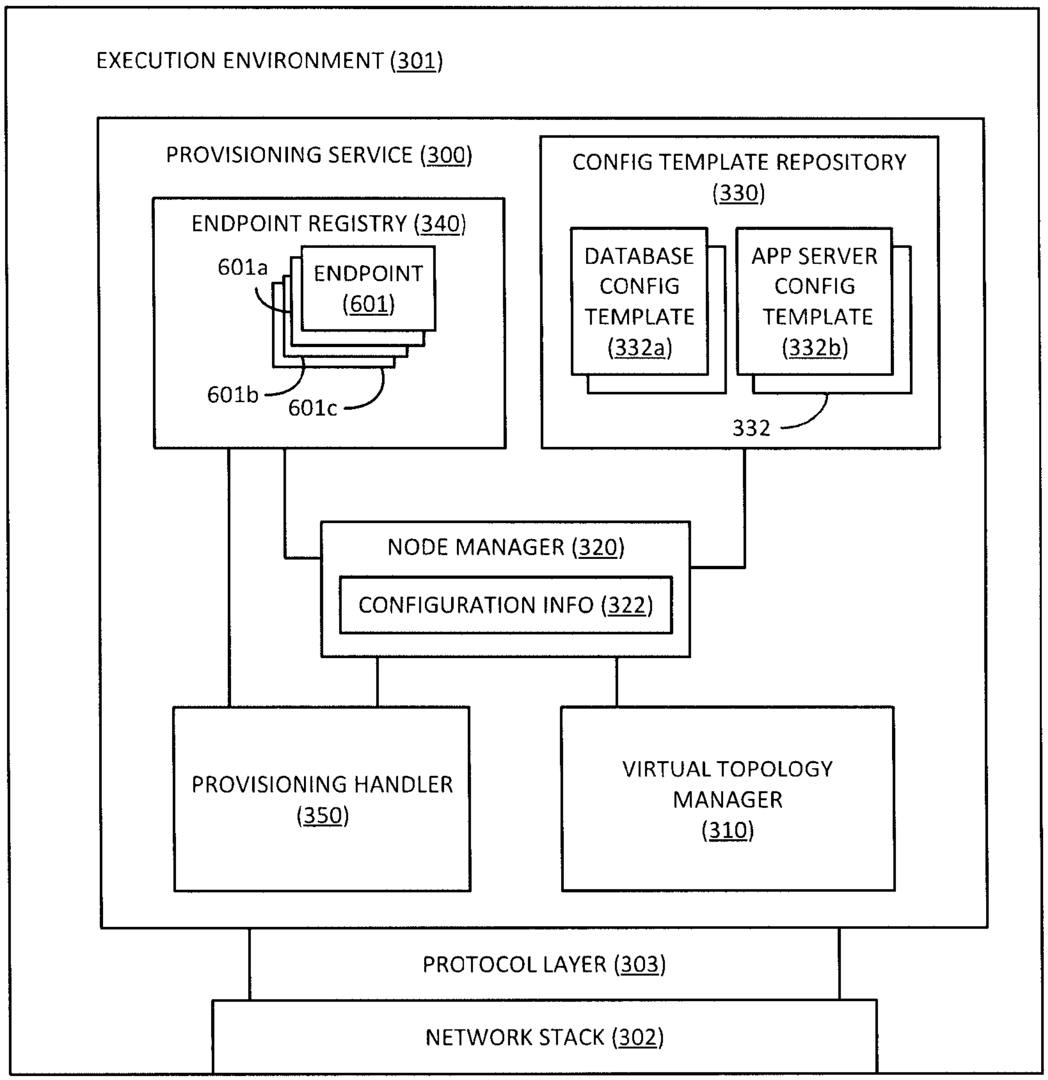

EXECUTION ENVIRONMENT (301)
PROVISIONING SERVICE (300)
CONFIG TEMPLATE REPOSITORY (330)
ENDPOINT REGISTRY (340)
601a
ENDPOINT (601)
601b
601c
DATABASE CONFIG TEMPLATE (332a)
APP SERVER CONFIG TEMPLATE (332b)
332
NODE MANAGER (320)
CONFIGURATION INFO (322)
PROVISIONING HANDLER (350)
VIRTUAL TOPOLOGY MANAGER (310)
PROTOCOL LAYER (303)
NETWORK STACK (302)

FIG. 3

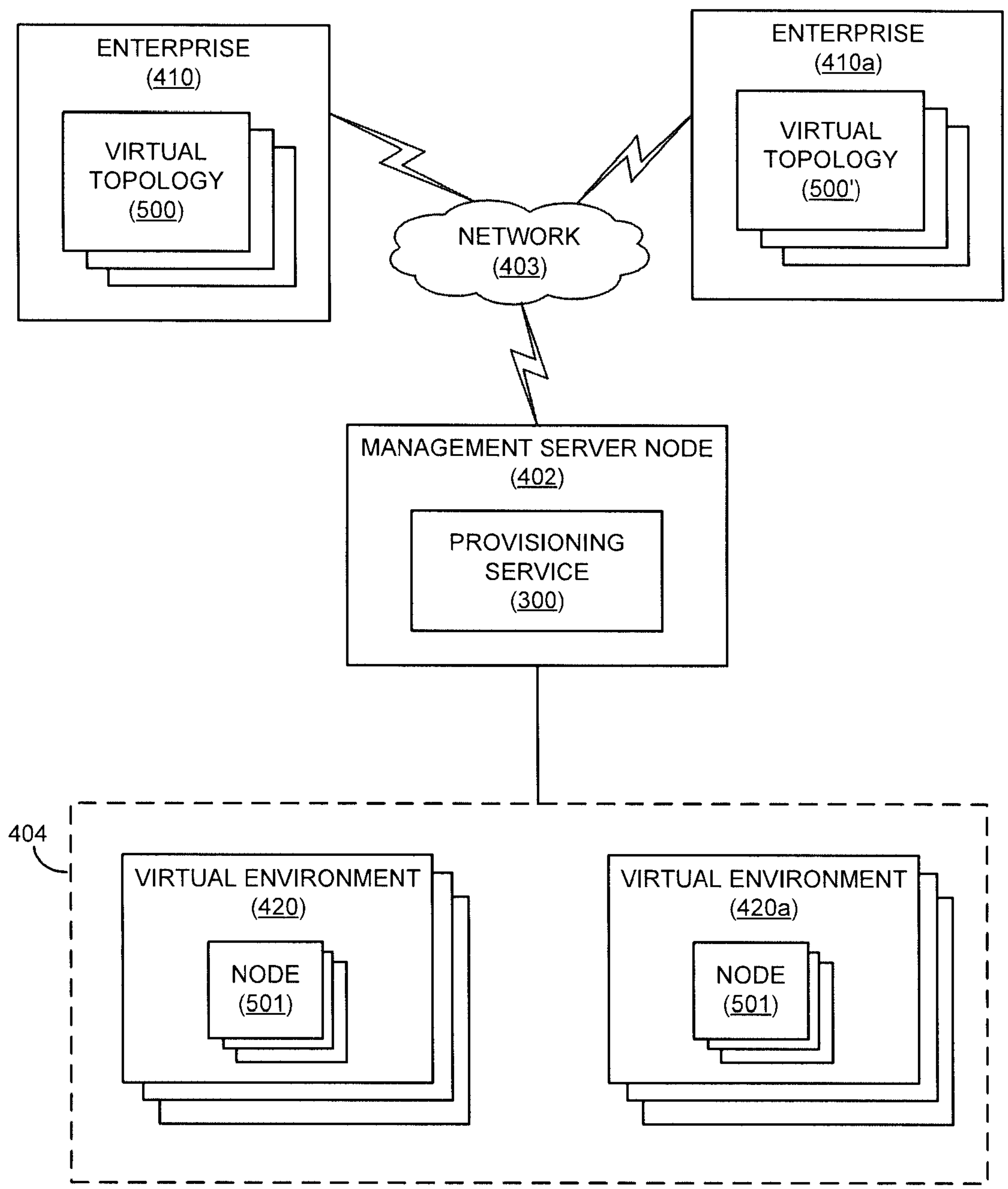

ENTERPRISE
(410)
VIRTUAL
TOPOLOGY
(500)
ENTERPRISE
(410a)
VIRTUAL
TOPOLOGY
(500')
NETWORK
(403)
MANAGEMENT SERVER NODE
(402)
PROVISIONING
SERVICE
(300)
404
VIRTUAL ENVIRONMENT
(420)
NODE
(501)
VIRTUAL ENVIRONMENT
(420a)
NODE
(501)

FIG. 4

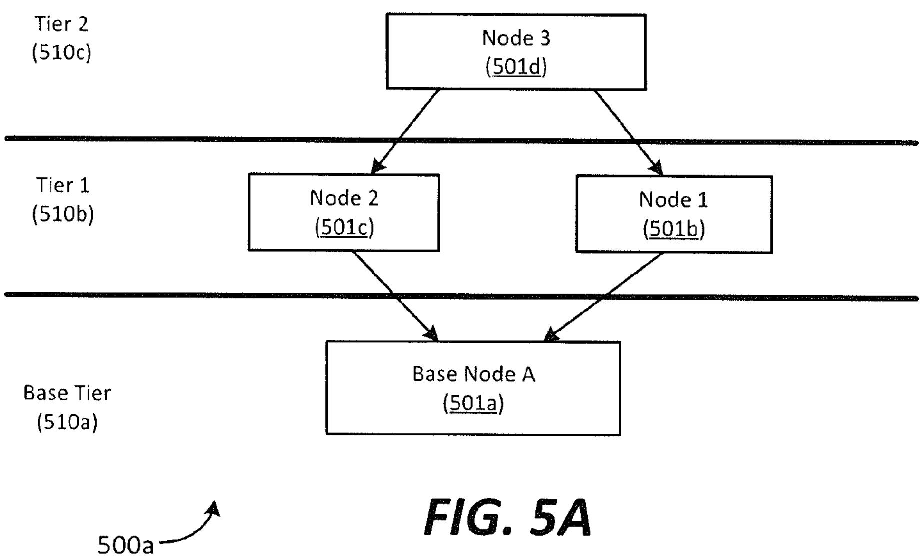


FIG. 5A

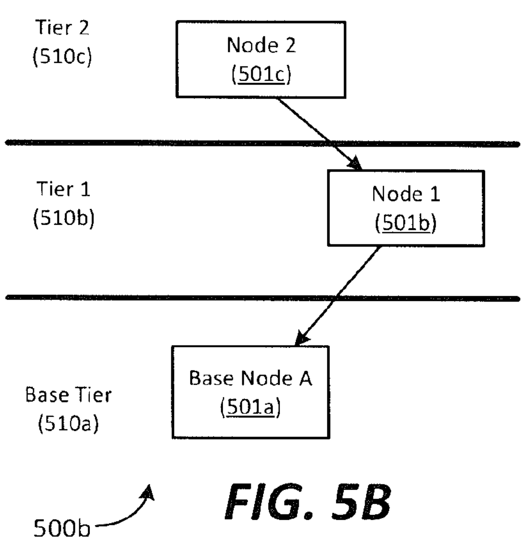


FIG. 5B

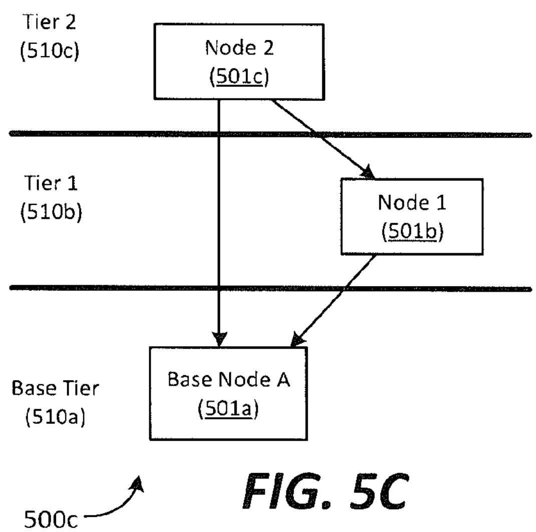


FIG. 5C

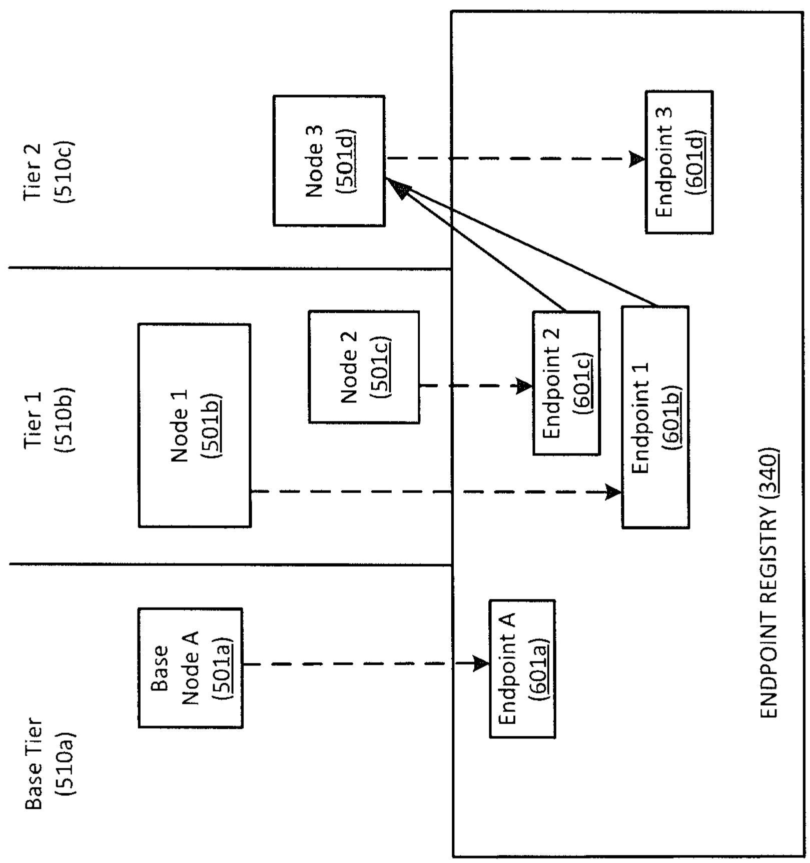

Base Tier
(510a)
Tier 1
(510b)
Tier 2
(510c)
Base
Node A
(501a)
Node 1
(501b)
Node 2
(501c)
Node 3
(501d)
Endpoint A
(601a)
Endpoint 1
(601b)
Endpoint 2
(601c)
Endpoint 3
(601d)
ENDPOINT REGISTRY (340)

FIG. 6B

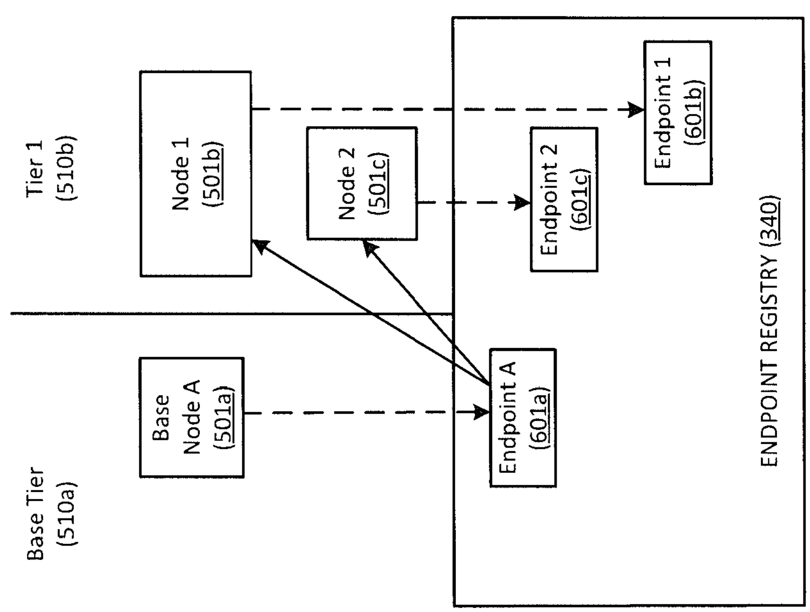
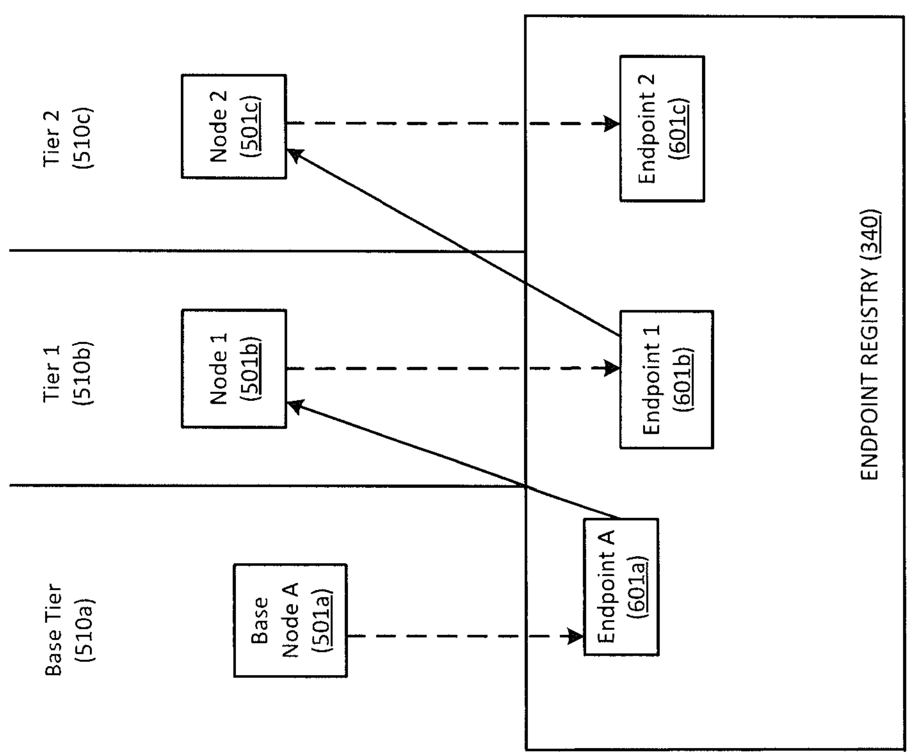
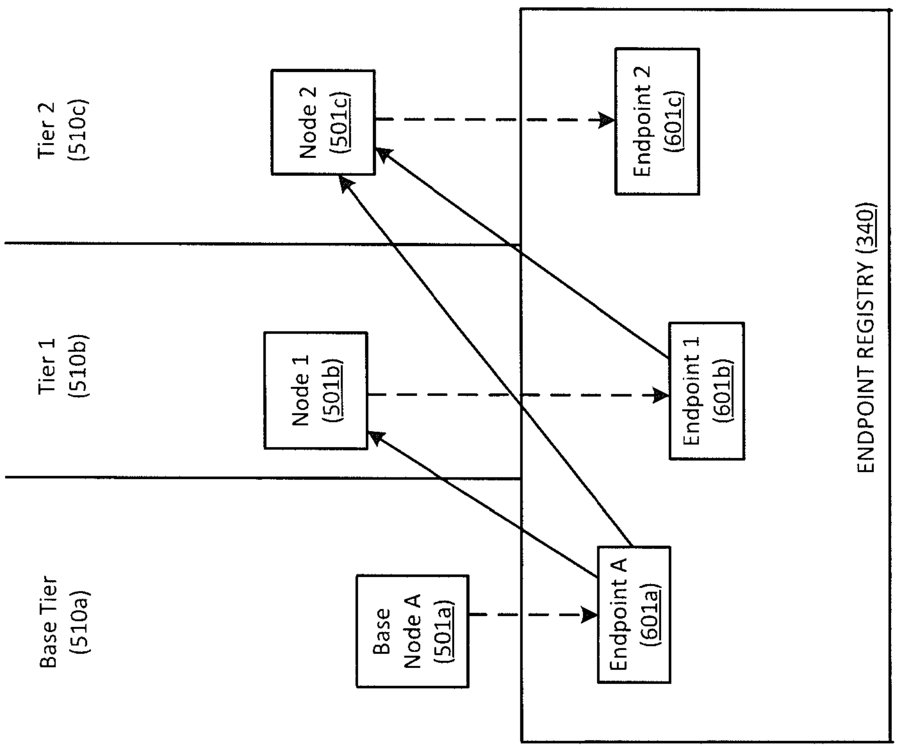

Base Tier
(510a)
Tier 1
(510b)
Base
Node A
(501a)
Node 1
(501b)
Node 2
(501c)
Endpoint A
(601a)
Endpoint 2
(601c)
Endpoint 1
(601b)
ENDPOINT REGISTRY (340)

FIG. 6A



Base Tier
(510a)
Tier 1
(510b)
Tier 2
(510c)
Base
Node A
(501a)
Node 1
(501b)
Node 2
(501c)
Endpoint A
(601a)
Endpoint 1
(601b)
Endpoint 2
(601c)
ENDPOINT REGISTRY (340)

FIG. 6C



Base Tier
(510a)
Tier 1
(510b)
Tier 2
(510c)
Base
Node A
(501a)
Node 1
(501b)
Node 2
(501c)
Endpoint A
(601a)
Endpoint 1
(601b)
Endpoint 2
(601c)
ENDPOINT REGISTRY (340)

FIG. 6D

PROVISION A VIRTUAL ENVIRONMENT BASED ON TOPOLOGY OF VIRTUAL NODES, NODE DEPENDENCIES AND BASE NODE CONFIGURATION INFORMATION

BACKGROUND

An enterprise computing environment typically includes a plurality of interconnected computing nodes, which can be physical and/or virtual nodes. Physical computing nodes, i.e., physical machines, can be clustered and/or distributed, that is, they can physically reside in a single location or be distributed in several locations, communicatively coupled to one another by a network, e.g., the Internet or a private network. Virtual computing nodes, on the other hand, represent physical machines, and many virtual nodes can typically be hosted by one physical machine. By virtualizing its computing environment, an enterprise can more efficiently manage its physical computing resources. In addition, an enterprise that owns physical machines can optimize its investment by "renting" its excess computing capacity to another enterprise which does not own physical machines.

While the virtualization of a computing environment offers numerous advantages, provisioning such an environment can present serious challenges. For instance, many enterprises require services and applications that rely on other services/applications, which, in a physical or virtual world, reside in different physical/virtual computing nodes, such as servers. Each node must be configured to support its service/application. For example, when a node hosts a web application, the node must be configured as an application server; and when a node hosts a database service, the node must be configured as a database server. Accordingly, depending on the hosted service/application, each node must be provisioned with specific parameters that support the hosted service/application.

Moreover, in most cases, the interconnectivity and dependencies between applications and services, and therefore, between different nodes, can be very complex. For example, when an application depends on a database service, the application server must be able to connect to and/or communicate with the database server. Accordingly, when provisioning such an environment, physical or virtual, each node that hosts a service that depends on another service must be configured with the correct connectivity information so that the node can communicate with the other node(s) hosting the other service.

Due to the variety of server specific configurations, and to the complexity of deployment topologies, provisioning and/or modifying such an environment, on demand or at runtime, is a very difficult and error prone task.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the subject matter claimed will become apparent to those skilled in the art upon reading this description in conjunction with the accompanying drawings, in which like reference numerals have been used to designate like elements, and in which:

FIG. **1** is a block diagram illustrating an exemplary hardware device in which the subject matter may be implemented;

FIG. **2** is a flow diagram illustrating a method for automatically provisioning a virtual computing environment according to an exemplary embodiment;

FIG. **3** is a block diagram illustrating a system for automatically provisioning a virtual computing environment according to an exemplary embodiment;

FIG. **4** illustrates a network in which a system for automatically provisioning a virtual computing environment can be implemented;

FIGS. **5**A, **5**B and **5**C are block diagrams representing exemplary network topologies according to an exemplary embodiment; and

FIGS. **6**A-**6**D are block diagrams illustrating representations of node provisioning according to an exemplary embodiment.

DETAILED DESCRIPTION

Methods and systems for automatically provisioning a virtual computing environment comprising a plurality of virtual computing nodes are disclosed. According to an embodiment, a provisioning service is configured to receive a virtual topology that defines virtual nodes associated with hierarchical tiers, and that defines dependencies between the virtual nodes. Starting with the lowest tier, referred to as a base tier, the provisioning service provisions a virtual node in the base tier, referred to as a base node, using configuration information specific to the base node. The configuration information includes a base endpoint that identifies interconnectivity parameters required to communicate with the base node. In an embodiment, when the base node is provisioned, the provisioning service copies the base endpoint and stores it in an endpoint registry.

Once the nodes in the base tier are provisioned, the provisioning service provisions a virtual node(s) in a tier hierarchically above the base tier. In an embodiment, for a first node, the provisioning service can determine that the first node depends on the base node based on the virtual topology. When this is the case, the provisioning service can, in an embodiment, retrieve the base endpoint associated with the base node from the endpoint registry, and can provision the first node using the base endpoint and configuration information specific to the first node. In an embodiment, the first node's configuration information also includes an endpoint that identifies interconnectivity parameters required to communicate with the first node. When the first node is provisioned, the provisioning service copies the associated endpoint and stores it in the endpoint registry.

The provisioning service can be configured, in an embodiment, to proceed in this manner for each of the virtual nodes in each of the tiers. Accordingly, each of the nodes can be provisioned automatically according to the virtual topology, and the endpoint registry stores, in an embodiment, an endpoint for each of the plurality of virtual nodes. Thus, if the virtual topology is modified, the virtual nodes can be reprovisioned easily and automatically. For example, when the dependency of a node is modified from a first node to a second node, the provisioning service can be configured to automatically retrieve the second node's endpoint from the registry, and to reprovision the node using the retrieved endpoint. Similarly, when a new node is added to the virtual topology and is provisioned, the new node's endpoint is stored in the registry, and can be retrieved to reprovision nodes that depend on the new node.

Prior to describing the subject matter in detail, an exemplary hardware device in which the subject matter may be implemented shall first be described. Those of ordinary skill in the art will appreciate that the elements illustrated in FIG. **1** may vary depending on the system implementation. With reference to FIG. **1**, an exemplary system for implementing the subject matter disclosed herein includes a physical or virtual hardware device **100**, including a processing unit **102**, memory **104**, storage **106**, data entry module **108**, display adapter **110**, communication interface **112**, and a bus **114** that couples elements **104-112** to the processing unit **102**. While many elements of the described hardware device **100** can be physically implemented, many if not all elements can also be virtually implemented by, for example, a virtual computing node.

The bus **114** may comprise any type of bus architecture. Examples include a memory bus, a peripheral bus, a local bus, etc. The processing unit **102** is an instruction execution machine, apparatus, or device, physical or virtual, and may comprise a microprocessor, a digital signal processor, a graphics processing unit, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), etc. The processing unit **102** may be configured to execute program instructions stored in memory **104** and/or storage **106** and/or received via data entry module **108**.

The memory **104** may include read only memory (ROM) **116** and random access memory (RAM) **118**. Memory **104** may be configured to store program instructions and data during operation of device **100**. In various embodiments, memory **104** may include any of a variety of memory technologies such as static random access memory (SRAM) or dynamic RAM (DRAM), including variants such as dual data rate synchronous DRAM (DDR SDRAM), error correcting code synchronous DRAM (ECC SDRAM), or RAMBUS DRAM (RDRAM), for example. Memory **104** may also include nonvolatile memory technologies such as nonvolatile flash RAM (NVRAM) or ROM. In some embodiments, it is contemplated that memory **104** may include a combination of technologies such as the foregoing, as well as other technologies not specifically mentioned. When the subject matter is implemented in a computer system, a basic input/output system (BIOS) **120**, containing the basic routines that help to transfer information between elements within the computer system, such as during start-up, is stored in ROM **116**.

The storage **106** may include a flash memory data storage device for reading from and writing to flash memory, a hard disk drive for reading from and writing to a hard disk, a magnetic disk drive for reading from or writing to a removable magnetic disk, and/or an optical disk drive for reading from or writing to a removable optical disk such as a CD ROM, DVD or other optical media. The drives and their associated computer-readable media provide nonvolatile storage of computer readable instructions, data structures, program modules and other data for the physical or virtual hardware device **100**.

It is noted that the methods described herein can be embodied in executable instructions stored in a computer readable medium for use by or in connection with an instruction execution machine, apparatus, or device, such as a computer-based or processor-containing machine, apparatus, or device. It will be appreciated by those skilled in the art that for some embodiments, other types of computer readable media may be used which can store data that is accessible by a computer, such as magnetic cassettes, flash memory cards, digital video disks, Bernoulli cartridges, RAM, ROM, and the like may also be used in the exemplary operating environment. As used here, a "computer-readable medium" can include one or more of any suitable media for storing the executable instructions of a computer program in one or more of an electronic, magnetic, optical, and electromagnetic format, such that the instruction execution machine, system, apparatus, or device can read (or fetch) the instructions from the computer readable medium and execute the instructions for carrying out the described methods. A non-exhaustive list of conventional exemplary computer readable medium includes: a portable computer diskette; a RAM; a ROM; an erasable programmable read only memory (EPROM or flash memory); optical storage devices, including a portable compact disc (CD), a portable digital video disc (DVD), a high definition DVD (HD-DVD™), a BLU-RAY disc; and the like.

A number of program modules may be stored on the storage **106**, ROM **116** or RAM **118**, including an operating system **122**, one or more applications programs **124**, program data **126**, and other program modules **128**. A user may enter commands and information into the device **100** through data entry module **108**. Data entry module **108** may include mechanisms such as a keyboard, a touch screen, a pointing device, etc. Other external input devices (not shown) are connected to the hardware device **100** via external data entry interface **130**. By way of example and not limitation, external input devices may include a microphone, joystick, game pad, satellite dish, scanner, or the like. In some embodiments, external input devices may include video or audio input devices such as a video camera, a still camera, etc. Data entry module **108** may be configured to receive input from one or more users of device **100** and to deliver such input to processing unit **102** and/or memory **104** via bus **114**.

A display **132** is also connected to the bus **114** via display adapter **110**. Display **132** may be configured to display output of device **100** to one or more users. In some embodiments, a given device such as a touch screen, for example, may function as both data entry module **108** and display **132**. External display devices may also be connected to the bus **114** via external display interface **134**. Other peripheral output devices, not shown, such as speakers and printers, may be connected to the device **100**.

The device **100** may operate in a networked environment using logical connections to one or more remote nodes (not shown) via communication interface **112**. The remote node may be another physical or virtual computer, a server, a router, a peer device or other common network node, and typically includes many or all of the elements described above relative to the device **100**. The communication interface **112** may interface with a wireless network and/or a wired network. Examples of wireless networks include, for example, a BLUETOOTH network, a wireless personal area network, a wireless 802.11 local area network (LAN), and/or wireless telephony network (e.g., a cellular, PCS, or GSM network). Examples of wired networks include, for example, a LAN, a fiber optic network, a wired personal area network, a telephony network, and/or a wide area network (WAN). Such networking environments are commonplace in intranets, the Internet, offices, enterprise-wide computer networks and the like. In some embodiments, communication interface **112** may include logic configured to support direct memory access (DMA) transfers between memory **104** and other devices.

In a networked environment, program modules depicted relative to the device **100**, or portions thereof, may be stored in a remote storage device, such as, for example, on a server. It will be appreciated that other hardware and/or software to establish a communications link between the device **100** and other devices may be used.

It should be understood that the arrangement of device **100** illustrated in FIG. **1** is but one possible implementation and that other arrangements are possible. It should also be understood that the various system components (and means) defined by the claims, described below, and illustrated in the various block diagrams represent logical components that are configured to perform the functionality described herein. For example, one or more of these system components can be realized, in whole or in part, by at least some of the components illustrated in the arrangement of device **100**. In addition, while at least one of these components are implemented at least partially as an electronic hardware component, and therefore constitutes a machine, the other components may be implemented in software, hardware, or a combination of software and hardware. More particularly, at least one component defined by the claims is implemented at least partially as an electronic hardware component, such as an instruction execution machine (e.g., a processor-based or processor-containing machine) and/or as specialized circuits or circuitry (e.g., discrete logic gates interconnected to perform a specialized function), such as those illustrated in FIG. **1**. Other components may be implemented in software, hardware, or a combination of software and hardware. Moreover, some or all of these other components may be combined, some may be omitted altogether, and additional components can be added while still achieving the functionality described herein. Thus, the subject matter described herein can be embodied in many different variations, and all such variations are contemplated to be within the scope of what is claimed.

In the description that follows, the subject matter will be described with reference to acts and symbolic representations of operations that are performed by one or more devices, unless indicated otherwise. As such, it will be understood that such acts and operations, which are at times referred to as being computer-executed, include the manipulation by the processing unit of data in a structured form. This manipulation transforms the data or maintains it at locations in the memory system of the computer, which reconfigures or otherwise alters the operation of the device in a manner well understood by those skilled in the art. The data structures where data is maintained are physical locations of the memory that have particular properties defined by the format of the data. However, while the subject matter is being described in the foregoing context, it is not meant to be limiting as those of skill in the art will appreciate that various of the acts and operation described hereinafter may also be implemented in hardware.

To facilitate an understanding of the subject matter described below, many aspects are described in terms of sequences of actions. At least one of these aspects defined by the claims is performed by an electronic hardware component. For example, it will be recognized that the various actions can be performed by specialized circuits or circuitry, by program instructions being executed by one or more processors, or by a combination of both. The description herein of any sequence of actions is not intended to imply that the specific order described for performing that sequence must be followed. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

Referring now to FIG. **2**, a flow diagram is presented illustrating a method for automatically provisioning a virtual computing environment comprising a plurality of virtual computing nodes according to an exemplary embodiment. FIG. **3** is a block diagram illustrating an exemplary system for automatically provisioning a virtual computing environment according to embodiments of the subject matter described herein. The method illustrated in FIG. **2** can be carried out by, for example, at least some of the components in the exemplary arrangement of components illustrated in FIG. **3**. The arrangement of components in FIG. **3** may be implemented by some or all of the components of the device **100** of FIG. **1**.

FIG. **3** illustrates components that are configured to operate within an execution environment hosted by a physical or virtual computer device and/or multiple computer devices, as in a distributed execution environment. For example, FIG. **4** illustrates a plurality of virtual computing environments **420**, **420***a* that comprise a plurality of virtual computing nodes **501** communicatively coupled to and managed by a management server node **402**. In an embodiment, the virtual computing environments **420**, **420***a* can be created in a cloud computing environment **404** provided by an independent cloud service provider that leases physical and/or virtual cloud resources to different private enterprises **410**, **410***a* for a fee. In that case, the management server node **402** can be a physical or virtual cloud resource in the public cloud environment **404** provided by the independent service provider. Alternatively, the management server node **402** can be in a demilitarized zone (not shown) associated with a secure enterprise network of an enterprise **410**, **410***a*. In an embodiment, the management server node **402** can be configured to provide an execution environment configured to support the operation of the components illustrated in FIG. **3** and/or their analogs.

Illustrated in FIG. **3** is a provisioning service **300** including components adapted for operating in an execution environment **301**. The execution environment **301**, or an analog, can be provided by a node such as the management server node **402**. The provisioning service **300** can include a configuration template repository **330** for storing configuration templates **332** for various types of services/applications hosted by the virtual computing nodes **501**, including, for example, a database service, a content management service, an HTTP service, a J2ee application service, a mail service, and the like. The configuration templates **332** can be preloaded into the repository **330** in an embodiment. Alternatively, or in addition, in another embodiment, the provisioning service **300** can be configured to receive customized and/or general configuration templates **332** from an enterprise **410** over a public or private network **403**.

According to an embodiment, the provisioning service **300** can also include a virtual topology manager **310** that is configured to receive a virtual topology **500** from an enterprise **410**. In an embodiment, the virtual topology **500** is a blueprint of the virtual environment **420** and defines a plurality of virtual nodes **501** associated with a plurality of hierarchical tiers, and defines dependencies between the virtual nodes **501**. According to an embodiment, at least one virtual node **501** can be associated with a tier, and a node in a tier can depend only on another node that is associated with a lower tier.

For example, FIG. **5**A is a graphical representation of an exemplary virtual topology **500***a* that includes virtual nodes **501***a*-**501***d* associated with three (3) hierarchical tiers **510***a*-**510***c*. The virtual topology **500***a* includes a virtual base node **501***a* associated with a lowest base tier **510***a*, and virtual nodes **501***b*-**501***d* associated with at least one tier **510***b*, **510***c* hierarchically above the lowest base tier **510***a*. The virtual base node **501***a* is an independent node that does not depend on another node, i.e., the virtual base node **501***a* hosts a service/application that is not configured to invoke or depend on other services/applications. An exemplary base node **501***a* can be, in an embodiment, a database server, a mail server, and/or an application server.

Virtual nodes **501***c*-**501***c***1** associated with higher tiers **510***b*, **510***c* above the lowest base tier **510***a* depend on at least one node in at least one lower tier. For example, Node **3** **501***d* associated with tier **2** **510***c* depends on Node **1** **501***b* and Node **2** **501***c*, both associated with tier **1** **510***b*, and Node **2** **501***c* depends on Base Node A **501***a* associated with the base tier **510***a*. In an embodiment, when a node, e.g., Node **3** **501***d*, depends on another node, e.g., Node **1** **501***b*, the dependent node **501***d* hosts an application/service that is configured to invoke or depend on a service/application hosted by the other node **501***b*. Thus, when the dependent node **501***d* is provisioned, it must be configured with the other node's connectivity information to connect to the other node **501***b*. Exemplary dependent nodes can be, in an embodiment, web servers, content management servers, application servers, and/or proxy servers.

According to an embodiment, the virtual topology **500***a* in FIG. **5**A can represent a simple web service environment, where Base Node A **501***a* is a database server, Node **1** **501***b* and Node **2** **501***c* are application servers, and Node **3** **501***d* is a proxy server. In this environment, the proxy server **510***d* sends service requests to both of the application servers **501***b*, **501***c*, which in turn, send requests to the database server **510***a*. Accordingly, the proxy server **510***d* depends on the applications servers **501***b*, **501***c*, which depend on the database server **501***a*.

According to an embodiment, an enterprise **410** can provide more than one virtual topology **500** corresponding to more than one virtual environment **420**. For example, different virtual topologies **500** can be implemented for different divisions or departments of an enterprise **410**. In another embodiment, the provisioning service **300** can be configured to provision and manage another set of virtual environments **420***a* for another enterprise **410***a*. The provisioning service **300** can be configured, in an embodiment, to receive the virtual topology **500**, **500'** over the private and/or public network **403**, such as the Internet, via a network stack **302** in the execution environment **301**. The network stack **302** can be configured to provide the virtual topology **500**, **500'** to a communication protocol layer **303**, which in turn can pass the information to the virtual topology manager **310**.

When the virtual topology, e.g., **500***a*, is received, the virtual topology manager **310** can be configured, in an embodiment, to analyze the virtual topology **500***a* to identify each virtual node **501***a*-**501***d* associated with each tier **510***a*-**510***c*, to determine which type of service/application each virtual node hosts, and to determine dependencies between the nodes **501***a*-**501***d*. According to an embodiment, once the virtual topology **500***a* has been analyzed, the node provisioning process begins starting with nodes associated with the lowest base tier **510***a* and continuing with nodes associated with a next higher tier **510***b* until all of the nodes **501***a*-**501***d* are provisioned.

Accordingly, with reference to FIG. **2**, in block **202**, a virtual base node is provisioned using base configuration information, which includes a base endpoint that identifies interconnectivity parameters required to communicate with the virtual base node. According to an embodiment, the provisioning service **300** includes a provisioning handler component **350** configured for provisioning a virtual base node, e.g., Base Node A **501***a*, using base configuration information that includes a base endpoint that identifies interconnectivity parameters required to communicate with the virtual base node **501***a*.

In an embodiment, when the virtual topology, e.g., **500***a*, is received and analyzed, the virtual topology manager **310** can be configured to select a virtual base node, e.g., **501***a*, and to invoke a node manager component **320** in the provisioning service **300**. The node manager component **320** can be configured, in an embodiment, to retrieve a configuration template **332** corresponding to the type of service/application hosted by the virtual base node **501***a*. For example, when the virtual base node **501***a* is a database server, the node manager component **320** can be configured to retrieve a database configuration template **332***a* from the configuration template repository **330**.

According to an embodiment, the configuration template **332** includes and/or identifies, in general, all data needed to provision a virtual node **501** according to a service associated with the configuration template **332**. In an embodiment, the configuration template **332** can include and/or identify the appropriate software, e.g., operating system, middleware and applications, for the service/application hosted by the virtual node **501**. For example, the database configuration template **332***a* can include and/or identify all data needed to provision a database server, while the application configuration template **332***b* can include and/or identify all data needed to provision an application server. In an embodiment, the node manager **320** can be configured to use the retrieved configuration template **332** to generate configuration information **322** for the service/application hosted by the virtual base node **501***a*.

In an embodiment, the node manager **320** can be configured to generate a base endpoint **601***a* associated with the virtual base node **501***a* that identifies interconnectivity parameters associated with the virtual base node **501***a* that are required to communicate with the base node **501***a*. For example, the interconnectivity parameters can identify a host, a communication port, a communication protocol, a username, and/or a password. In some cases, a connection URL and/or an encryption type and keys can also be identified. According to an embodiment, the base endpoint **601***a* of the virtual base node **501***a* can be associated with the virtual base node **501***a* because the combination of the interconnectivity parameters is specific to the base node **501***a*.

According to an embodiment, the node manager **320** can be configured to collect connectivity information relating to other nodes **501** upon which the virtual base node **501***a* depends. Nevertheless, because the virtual base node **501***a* is associated with the lowest base tier **510***a*, it does not depend on another node, and therefore, no such connectivity information exists. According to an embodiment, the node manager **320** can be configured to include the base endpoint **601***a* in the configuration information **322** for the virtual base node **501***a*, and can be configured to provide the configuration information **322** to the provisioning handler component **350**.

According to an embodiment, the provisioning handler component **350** can be configured to provision the virtual base node **501***a* using the configuration information **322** for the base node **501***a* received from the node manager **320**. For example, in an embodiment, the provisioning handler component **350** can be configured to "load" the identified software, e.g., the operation system, device drivers, middleware and applications, to customize and configure the system and the software to create a boot image for the server, and to perform other provisioning tasks necessary to prepare the virtual base node **501***a* for operation.

Referring again to FIG. **2**, once the virtual base node **501***a* is provisioned, the base endpoint **601***a* is stored in an endpoint registry **340** associated with the provisioning service **300** in block **204**. In an embodiment, the provisioning handler component **350** can be configured to store the base endpoint **601***a* in the endpoint registry **340** after it has provisioned the virtual base node **501***a*. Alternatively, the node manager component **320** can be configured to copy the base endpoint **601***a* when it is generated, and to store it in the endpoint registry **340**.

In an embodiment, the provisioning handler **350** can be configured to provision all virtual nodes **501** associated with the lowest base tier **510***a* in the manner described above, and to store each of the corresponding base endpoints **601** in the endpoint registry **340**. When each of the virtual nodes **501** in the lowest base tier **510***a* are provisioned, the virtual topology manager **310** can be configured to progress to a next tier immediately above the completed base tier **510***a*, and to select a virtual first node, e.g., Node 1 **501**_b_, associated with the next tier immediately above the base tier **510**_a_, i.e., the first tier **510**_b_, for provisioning.

Referring again to FIG. **2**, when a virtual first node **501**_c_ is selected, the virtual topology manager **310** can be configured to determine, in block **206**, that the virtual first node **501**_b_ depends on the virtual base node **501**_a_. According to an embodiment, the virtual topology manager **310** can be configured to make this determination based on the virtual topology, e.g., **500**_a_, which as stated above, defines the dependencies between the virtual nodes **501**_a_-**501**_d_. For example, the virtual topology **500**_a_ represented in FIG. **5**A indicates that the virtual first node, e.g., Node **1 501**_b_, depends on the virtual base node, Base Node A **501**_a_. Once the virtual first node **501**_b_ is selected and its dependency determined, the virtual topology manager **310** can invoke the node manager component **320**.

In an embodiment, when invoked, the node manager component **320** can retrieve a configuration template **332** corresponding to the type of service/application hosted by the virtual first node **501**_b_, and can use the retrieved configuration template **332** to generate configuration information **322** for the service/application hosted by the virtual first node **501**_b_. A first endpoint **601**_b_ associated with the virtual first node **501**_b_ is also generated and included in the configuration information **322**. Similar to the base endpoint **601**_a_, the first endpoint **601**_b_ identifies interconnectivity parameters associated with the virtual first node **501**_b_ that are required to communicate with the virtual first node **501**_b_.

As stated above, in addition to generating the endpoint **601**, the node manager component **320** collects connectivity information relating to node(s) **501** on which the virtual first node **501**_b_ depends. In this case, the virtual first node **501**_b_ depends on the virtual base node **501**_a_, and therefore, the connectivity information relating to the virtual base node **501**_a_ is collected. In an embodiment, the base endpoint **601**_a_ includes the connectivity information relating to the virtual base node **501**_a_.

Accordingly, referring again to FIG. **2**, the node manager component **320** is configured to retrieve the base endpoint **601**_a_ associated with the virtual base node **501**_a_ from the endpoint registry **340** in block **208**. In an embodiment, the node manager **320** can be configured to provide the retrieved base endpoint **601**_a_ and the configuration information **322** for the virtual first node **501**_b_ to the provisioning handler component **350**, which is configured for provisioning the virtual first node **501**_b_ in block **210**. According to an embodiment, the first configuration information **322** for the virtual first node **501**_b_ and the base endpoint **601**_a_ are used to provision the virtual first node **501**_b_. As described above, once the virtual first node **501**_b_ is provisioned, the first endpoint **601**_b_ is stored in the endpoint registry **340** along with the base endpoint **601**_a_.

FIG. **6**A is a graphical representation of the provisioning of the base virtual node, e.g., Base Node A **501**_a_, the virtual first node, e.g., Node **1 501**_b_, and a virtual second node, e.g., Node **2 501**_c_, of FIG. **5**A. As is shown in FIG. **6**A, Node **1 501**_b_ is provisioned using Endpoint A **601**_a_ associated with Base Node A **501**_a_ on which Node **1 501**_b_ depends (as indicated by the solid arrow from Endpoint A **601**_a_ to Node **1 501**_b_). In addition, Endpoint **1 601**_b_ associated with Node **1 501**_b_ is stored in the endpoint registry **340** (as indicated by the dashed arrow from Node **1 501**_b_ to Endpoint **1 601**_b_).

In an embodiment, the provisioning handler **350** can be configured to provision the virtual second node, e.g., Node **2 501**_c_, in the manner described above with regard to the virtual first node **501**_b_. As is shown in the topology **500**_a_ represented in FIG. **5**A, Node **1 501**_b_ and Node **2 501**_c_ depend on the same virtual base node, e.g., Base Node A **501**_a_, and therefore, base Endpoint A **601**_a_ is retrieved again and used again to provision Node **2 501**_c_, as is shown in FIG. **6**A. As described above, once the virtual second node **501**_c_ is provisioned, its endpoint **601**_c_ is stored in the endpoint registry **340** along with the Endpoint **1 601**_b_ and base Endpoint A **601**_a_.

As before, the provisioning handler **350** can be configured to provision all virtual nodes **501** associated with the first tier **510**_b_ in the manner described above, and to store each of the corresponding base endpoints **601** in the endpoint registry **340**. When each of the virtual nodes **501** in the first tier **510**_b_ are provisioned, the virtual topology manager **310** can be configured to provision virtual nodes **501** associated with a second tier **510**_c_ immediately above the completed first tier **510**_b_.

For example, referring again to the topology **500**_a_ in FIG. **5**A, the virtual topology manager **310** can be configured to select a virtual third node, e.g., Node **3 501**_d_, associated with the second tier **510**_b_, and to determine, based on the topology **500**_a_, that Node **3 501**_d_ depends on two virtual nodes, Node **1 501**_b_ and Node **2 501**_c_, in a lower tier **510**_b_. In this case, two endpoints, Endpoint **1 601**_b_ and Endpoint **2 601**_c_, are retrieved and used to provision Node **3 501**_d_, as is shown in FIG. **6**B. Once the virtual third node **501**_d_ is provisioned, its endpoint **601**_d_ is stored in the endpoint registry **340** along with the other endpoints **601**_a_-**601**_c_.

In an embodiment, when each of the virtual nodes **501** in a tier are provisioned, the virtual topology manager **310** can be configured to provision virtual nodes **501** associated with a next tier immediately above the completed tier, and to continue with each progressively higher tier until each of the plurality of virtual nodes **501** of the virtual environment **420** is provisioned. When provisioning of the virtual environment **420** is completed, endpoints **601** associated with each of the plurality of virtual nodes **501** are stored in the endpoint repository **340**. Accordingly, when the virtual topology **500** of the virtual environment **420** is modified, and the dependencies between the nodes **501** are changed, the provisioning service **300** can easily reprovision the virtual environment **420** by receiving and using the appropriate endpoints **601** to reprovision the affected virtual nodes **501**.

For example, FIG. **5**B is a graphical representation of another virtual topology **500**_b_ where Node **2 501**_c_ depends on Node **1 501**_b_, and Node **1 501**_b_ depends on Base Node A **501**_a_. FIG. **6**C is a graphical representation of the provisioning of the virtual nodes **501**_a_-**501**_c_ of FIG. **5**B, and illustrates that Node **1 501**_b_ is provisioned using Endpoint A **601**_a_ of Base Node A **501**_a_, and Node **2 501**_c_ is provisioned using Endpoint **1 601**_b_ of Node **1 501**_b_. In an embodiment, the topology **500**_b_ can be modified so that Node **2 501**_c_ depends on Base Node A **501**_a_ in addition to Node **1 501**_b_. FIG. **5**C is a graphical representation of the modified topology **500**_c_. When the provisioning service **300** receives an indication modifying the topology in this manner, the provisioning service **300** can automatically reprovision the affected node, e.g., Node **2 501**_c_, by receiving the endpoints **601** of Base Node A **501**_a_ and Node **1 501**_b_ from the endpoint registry **340**, and using the retrieved endpoints **601**_a_, **601**_b_ to reprovision Node **2 501**_c_. FIG. **6**D graphically illustrates the reprovisioning of Node **2 501**_c_ according to an exemplary embodiment.

According to aspects of exemplary embodiments, an endpoint that identifies interconnectivity parameters required to communicate with a virtual node is generated for each of a plurality of virtual nodes in a virtual environment, and is stored in an endpoint repository. Using the endpoints, any virtual environment represented by a virtual topology can be easily and automatically provisioned. Moreover, when the virtual topology is modified, the affected nodes can be reprovisioned easily and automatically as well.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the subject matter (particularly in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation, as the scope of protection sought is defined by the claims as set forth hereinafter together with any equivalents thereof entitled to. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illustrate the subject matter and does not pose a limitation on the scope of the subject matter unless otherwise claimed. The use of the term "based on" and other like phrases indicating a condition for bringing about a result, both in the claims and in the written description, is not intended to foreclose any other conditions that bring about that result. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention as claimed.

Preferred embodiments are described herein, including the best mode known to the inventor for carrying out the claimed subject matter. Of course, variations of those preferred embodiments will become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventor expects skilled artisans to employ such variations as appropriate, and the inventor intends for the claimed subject matter to be practiced otherwise than as specifically described herein. Accordingly, this claimed subject matter includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed unless otherwise indicated herein or otherwise clearly contradicted by context.

What is claimed is:

1. A method for automatically provisioning a virtual computing environment comprising a plurality of virtual computing nodes, the method comprising:

receiving, a virtual topology associated with at least one virtual environment, the virtual topology comprising a plurality of virtual nodes;

analyzing the received virtual topology to identify dependencies between the plurality of nodes and at least one of a service and an application hosted by each virtual node;

identifying a virtual base node from the virtual topology, the virtual base node being one of the plurality of virtual nodes;

provisioning the identified virtual base node using base configuration information, wherein the base configuration information includes a base endpoint that identifies interconnectivity parameters required to communicate with the virtual base node;

storing the base endpoint in an endpoint registry;

determining, from the virtual topology, that a virtual first node depends on the virtual base node;

retrieving the base endpoint from the endpoint registry based on the determination that the virtual first node depends on the virtual base node;

provisioning the virtual first node using the retrieved base endpoint and first configuration information for the virtual first node, the first configuration information including a first endpoint; and

storing a first endpoint in the endpoint registry.

2. The method of claim **1** further comprising:

determining that a virtual second node also depends on the virtual base node;

receiving the base endpoint from the endpoint registry; and

provisioning the virtual second node using the retrieved base endpoint and second configuration information for the virtual second node.

3. The method of claim **2** wherein the first endpoint identifies interconnectivity parameters required to communicate with the virtual first node, and the second configuration information includes a second endpoint that identifies interconnectivity parameters required to communicate with the second virtual node, the method further comprising storing the first endpoint and the second endpoint in the endpoint registry.

4. The method of claim **3** further comprising:

determining that a virtual third node depends on the virtual first node and the virtual second node;

receiving the first endpoint and the second endpoint from the endpoint registry; and

provisioning the virtual third node using the retrieved first endpoint and second endpoint, and third configuration information for the virtual third node.

5. The method of claim **4** wherein the virtual third node represents a proxy server, the virtual first and second nodes represent first and second application servers, and the virtual base node represents a database server.

6. The method of claim **1** wherein the first endpoint identifies interconnectivity parameters required to communicate with the virtual first node.

7. The method of claim **6** further comprising:

determining that a virtual second node depends on the virtual first node;

receiving the first endpoint from the endpoint registry; and

provisioning the virtual second node using the retrieved first endpoint, and second configuration information for the virtual second node.

8. The method of claim **7** further comprising:

receiving an indication that the virtual second node depends on the virtual base node and on the virtual first node;

receiving the base endpoint and the first endpoint from the endpoint registry; and

reprovisioning the virtual second node using the retrieved endpoints.

9. The method of claim **1** wherein the interconnectivity parameters identify at least one of a host, a port, a protocol, a username, and a password.

10. A computer program product comprising a non-transitory machine-readable medium carrying one or more sequences of instructions for automatically provisioning a virtual computing environment comprising a plurality of virtual computing nodes, which instructions, when executed by one or more processors, cause the one or more processors to carry out the steps of:

receiving, a virtual topology associated with at least one virtual environment, the virtual topology comprising a plurality of virtual nodes;

analyzing the received virtual topology to identify dependencies between the plurality of nodes and at least one of a service and an application hosted by each virtual node;

identifying a virtual base node from the virtual topology, the virtual base node being one of the plurality of virtual nodes;

provisioning the identified virtual base node using base configuration information, wherein the base configuration information includes a base endpoint that identifies interconnectivity parameters required to communicate with the virtual base node;

storing the base endpoint in an endpoint registry;

determining, from the virtual topology, that a virtual first node depends on the virtual base node;

retrieving the base endpoint from the endpoint registry based on the determination that the virtual first node depends on the virtual base node;

provisioning the virtual first node using the retrieved base endpoint and first configuration information for the virtual first node, the first configuration information including a first endpoint; and

storing a first endpoint in the endpoint registry.

11. A system for automatically provisioning a virtual computing environment comprising a plurality of virtual computing nodes, the apparatus comprising:

a processor; and

one or more stored sequences of instructions which, when executed by the processor, cause the processor to carry out the steps of:

receiving, a virtual topology associated with at least one virtual environment, the virtual topology comprising a plurality of virtual nodes;

analyzing the received virtual topology to identify dependencies between the plurality of nodes and at least one of a service and an application hosted by each virtual node;

identifying a virtual base node from the virtual topology, the virtual base node being one of the plurality of virtual nodes;

provisioning the identified virtual base node using base configuration information, wherein the base configuration information includes a base endpoint that identifies interconnectivity parameters required to communicate with the virtual base node;

storing the base endpoint in an endpoint registry;

determining, from the virtual topology, that a virtual first node depends on the virtual base node;

retrieving the base endpoint from the endpoint registry based on the determination that the virtual first node depends on the virtual base node;

provisioning the virtual first node using the retrieved base endpoint and first configuration information for the virtual first node, the first configuration information including a first endpoint; and

storing a first endpoint in the endpoint registry.

12. The system of claim **11** further comprising stored instructions for:

determining that a virtual second node also depends on the virtual base node;

receiving the base endpoint from the endpoint registry; and

provisioning the virtual second node using the retrieved base endpoint and second configuration information for the virtual second node.

13. The system of claim **12** wherein first endpoint that identifies interconnectivity parameters required to communicate with the virtual first node, and the second configuration information includes a second endpoint that identifies interconnectivity parameters required to communicate with the second virtual node, the system further comprising stored instructions for storing the first endpoint and the second endpoint in the endpoint registry.

14. The system of claim **13** further comprising stored instructions for:

determining that a virtual third node depends on the virtual first node and the virtual second node;

receiving the first endpoint and the second endpoint from the endpoint registry; and

provisioning the virtual third node using the retrieved first endpoint and second endpoint, and third configuration information for the virtual third node.

15. The system of claim **14** wherein the virtual third node represents a proxy server, the virtual first and second nodes represent application servers, and the virtual base node represents a database server.

16. The system of claim **15** wherein the virtual base node is provisioned prior to provisioning any virtual nodes that depend on the virtual base node, and the virtual first node is provisioned prior to provisioning any virtual nodes that depend on the virtual first node.

17. The system of claim **11** wherein the first configuration information includes a first endpoint that identifies interconnectivity parameters required to communicate with the virtual first node.

18. The system of claim **17** further comprising stored instructions for:

determining that a virtual second node depends on the virtual first node;

receiving the first endpoint from the endpoint registry; and

provisioning the virtual second node using the retrieved first endpoint, and second configuration information for the virtual second node.

19. The system of claim **18** further comprising stored instructions for:

receiving an indication that the virtual second node depends on the virtual base node and on the virtual first node;

receiving the base endpoint and the first endpoint from the endpoint registry; and

reprovisioning the virtual second node using the retrieved endpoints.

20. The system of claim **11** wherein the interconnectivity parameters identify at least one of a host, a port, a protocol, a username, and a password.

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